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A METHOD FOR THE NONDIMENSIONAL COMPARISON OF MIXED LAYER MODEL--ETC(U)

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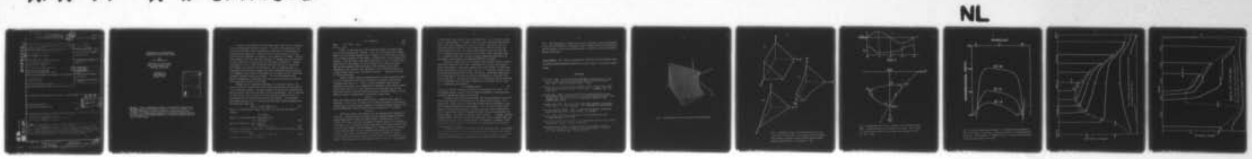

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A METHOD FOR THE NONDIMENSIONAL COMPARISON OF MIXED LAYER MODELS

by
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submitted to
Ocean Modeling
15 April 1977

Abstract Using a dimensional analysis, a standardized framework for the intercomparison of different theoretical models is derived. This framework should also be useful in empirical data evaluations and ultimately in differentiating between the alternative parameterizations for the deepening and retreat process of the oceanic planetary boundary layer or mixed layer.

A number of one-dimensional mixed-layer models based upon the turbulent kinetic energy budget have been proposed. Typically, these models are calibrated or verified by running them against a time series of observations of layer depth and temperature. However, when the initial conditions and the surface forcing conditions are changed, a new calibration is needed. The most recent models, which have more than one degree of freedom, have the potential of being tuned to fit a more general and wide range of conditions. Running such models in time in order to achieve calibration results in uncertainty with regard to the precision of the results. What is suggested here is a standardized nondimensional framework for model comparisons and data analysis. This framework should identify (independent of the values for the calibration constants) features unique to each model. This will then indicate what specific information is needed from the data to prove or disprove the theoretical hypotheses entailed in each model.

Perhaps the most important requirement of mixed-layer models is the ability to properly simulate the rate of deepening, $dh/dt > 0$, and the eventuality of retreat, $dh/dt \leq 0$. The major features of the seasonal pycnocline and the sea-surface temperature may then be closely approximated. What is required to predict $h(t)$, given a particular initial buoyancy or density profile, is the buoyancy flux at the base of the mixed layer, $\overline{bw}(-h)$. If the modeled entrainment buoyancy flux is a function of wind stress, surface buoyancy flux and mixed-layer depth only,

$$\overline{bw}(-h) = F_1[u_*^2, \overline{bw}(0), h] , \tag{1}$$

then, in a nondimensional context, the model will have only one degree of freedom,

$$P^* = P^*(H^*) ,$$

where P^* is the dimensionless entrainment flux,

$$P^* = -\overline{bw}(-h)h/u_*^3 , \tag{2}$$

and H^* is a measure of layer stability,

$$H^* = -\overline{bw}(0)h/u_*^3 = h/L_1 \tag{3}$$

where L_1 is the Obukhov length scale. Including the coriolis parameter in the functional relationship,

$$\overline{bw}(-h) = F_2[f, u_*^2, \overline{bw}(0), h] , \tag{1a}$$

introduces a second degree of freedom,

$$P^* = P^*(Z^*,H^*) \tag{2a}$$

where $$Z^* = hf/u_* = h/L_2 \tag{4}$$

with $L_2 = u_*/f$.

Figure 1 is the solution to the mixed-layer model of Garwood (1976), cast in this nondimensional framework. Here, Z^* is the inverse of a Rossby number for the turbulent boundary layer. However, it is most useful to think of Z^* as being a measure of layer depth. Although there is some corroborative evidence, it has not been conclusively shown that $L_2 = u_*/f$ is a significant length scale in the dynamics for the turbulence of the ocean mixed layer. What has been suggested (Gill and Turner, 1975; Elsberry, et al, 1976; Resnyanskiy, 1975; Garwood, 1976; and others) is the likely existence of a second limiting length scale, particularly for deep . neutral or unstable ($L_1^{-1} \lesssim 0$) mixed layers.

Figure 1 readily reveals the characteristics of this particular model. The rate of entrainment (P^*) falls off with both increased stability and increased layer depth (Z^*). The $P^* = 0$ locus represents layer retreat. According to the model, it is theoretically impossible to have (Z^*,H^*) coordinates to the right of this line. Where this line intersects the H^* axis, mixed-layer retreat would be largely attributable to buoyant damping, and the depth of retreat is proportional to the Obukhov length scale,

$$h_r \propto L_1 \quad .$$

Where the retreat locus intersects the Z^* axis, a neutral steady state is predicted. In this case, the depth of the turbulent boundary layer would be controlled by the rate of shear production of turbulent kinetic energy ($\propto u_*^3$) and the theoretical limiting time scale for dissipation ($\propto f^{-1}$), giving

$$h_r \propto u_*/f \quad .$$

Three other models have been fit into the nondimensional framework of $P^*(Z^*,H^*)$. Figure 2a shows the solution to the prototype turbulent kinetic energy budget model of Kraus and Turner (1967). As may be seen, P^* is a funcion of H^* alone. With but one degree of freedom, there is no decrease in entrainment rate attributable to layer depth alone, and retreat may occur only with sufficient negative surface buoyancy flux. Recognizing this limitation in the prototype model for use in simulating mixing during storm events, Elsberry, et al (1976) parameterized a dissipation enhancement effect by assuming that shear production minus dissipation falls off exponentially with depth. The configuration for this model is shown in Fig. 2b. The curvature

of the retreat locus resembles that of Garwood, Fig. 1, but a neutral steady state is not predicted. Kim (1976), with a constant "background dissipation" term, alters the prototype model to give a solution, depicted in Fig. 2c, which does predict a possible neutral steady state, with the retreat locus intersecting the Z* axis. All three of these models also differ from the Fig. 1 solution in that they all pose P* as having a linear dependence upon H*. In Garwood (1976), the fraction of buoyant production contributing to entrainment is not constant and therefore $\partial P^*/\partial H^* \neq$ constant.

A cyclical steady state is also possible for any model having a retreat locus which intersects the Z* axis. Starting with a neutral mean buoyancy profile and imposing a sinusoidal buoyancy flux at the surface, a closed loop will be prescribed in the Z*-H* plane. See Fig. 3. Initially, retreat occurs during the first quarter [0-1] of the cycle period. Entrainment takes place for the remainder of the time, but the rate of deepening is slow until the last quarter [3-4]. The particular shape of this closed loop and the resultant h(t) are dependant upon the relative magnitudes of the length scales L_1 and L_2 , as measured by the parameter

$$B^* = |\overline{bw}(0)| /(fu_*^2) \quad . \tag{5}$$

In Fig.4, a large B* reflects a relatively strong buoyancy flux cycle. For increasingly smaller values of B*, the response approaches a simple perturbation about the neutral steady state solution.

Of course, the real ocean experiences more than one buoyancy flux cycle. The two most obvious of these cycles are the annual and the diurnal. The annual cycle shown in Fig. 6 is the model solution for the evolution in time of the seasonal thermocline at OWS November. It is this cycle which is most apparent in historical BT records. One would very much like to analyze this data in terms of the P*(Z*,H*) framework in order to discriminate between the various models. The problem is that the diurnal cycle is stronger and thus largely controls the value of P* at any given time. Figure 7 demonstrates the mixed-layer response to this diurnal cycle. The pattern is analogous to that of the annual cycle, but it is a difficult task to reconstruct this pattern from mechanical BT records.

In conclusion, this is a difficult but not impossible task. For example, in Fig. 8, data supplied by Camp (1976) has been used to define a mean Obukhov length scale based upon the daily mean of the surface buoyancy flux. The data points in the $\overline{Z^*}$-$\overline{H^*}$ plane are positioned so as to tend to define a retreat

locus. The values of $\overline{P^*}$, averaged over one day, only have a weak correspondence to the value of $P^*(\overline{Z^*},\overline{H^*})$. Definition of the P* surface itself will be possible only by analysis of the diurnal response under a variety of initial and surface boundary conditions.

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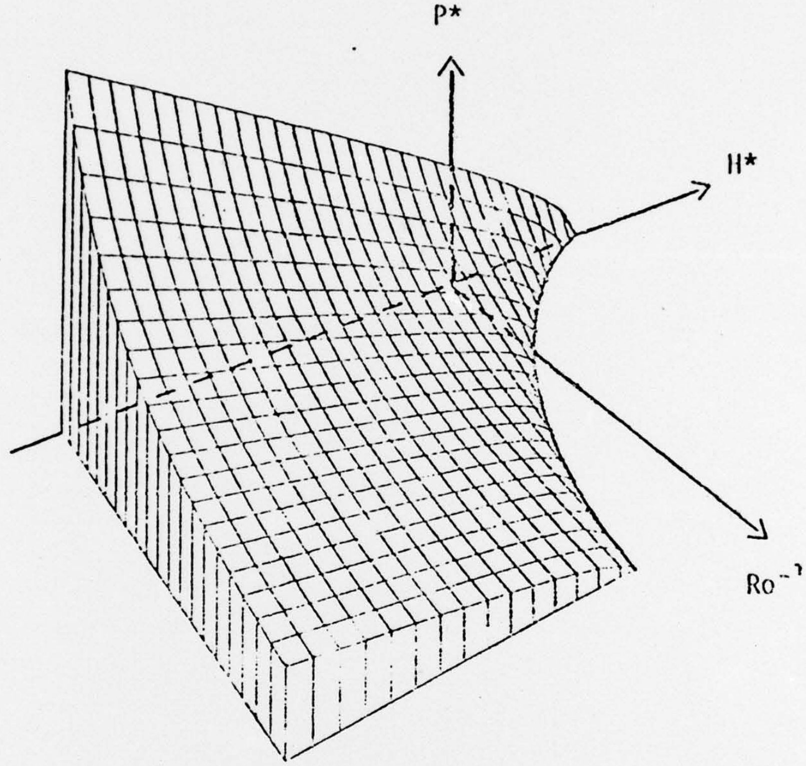


Fig. 1 Nondimensional solution to model by Garwood (1976).

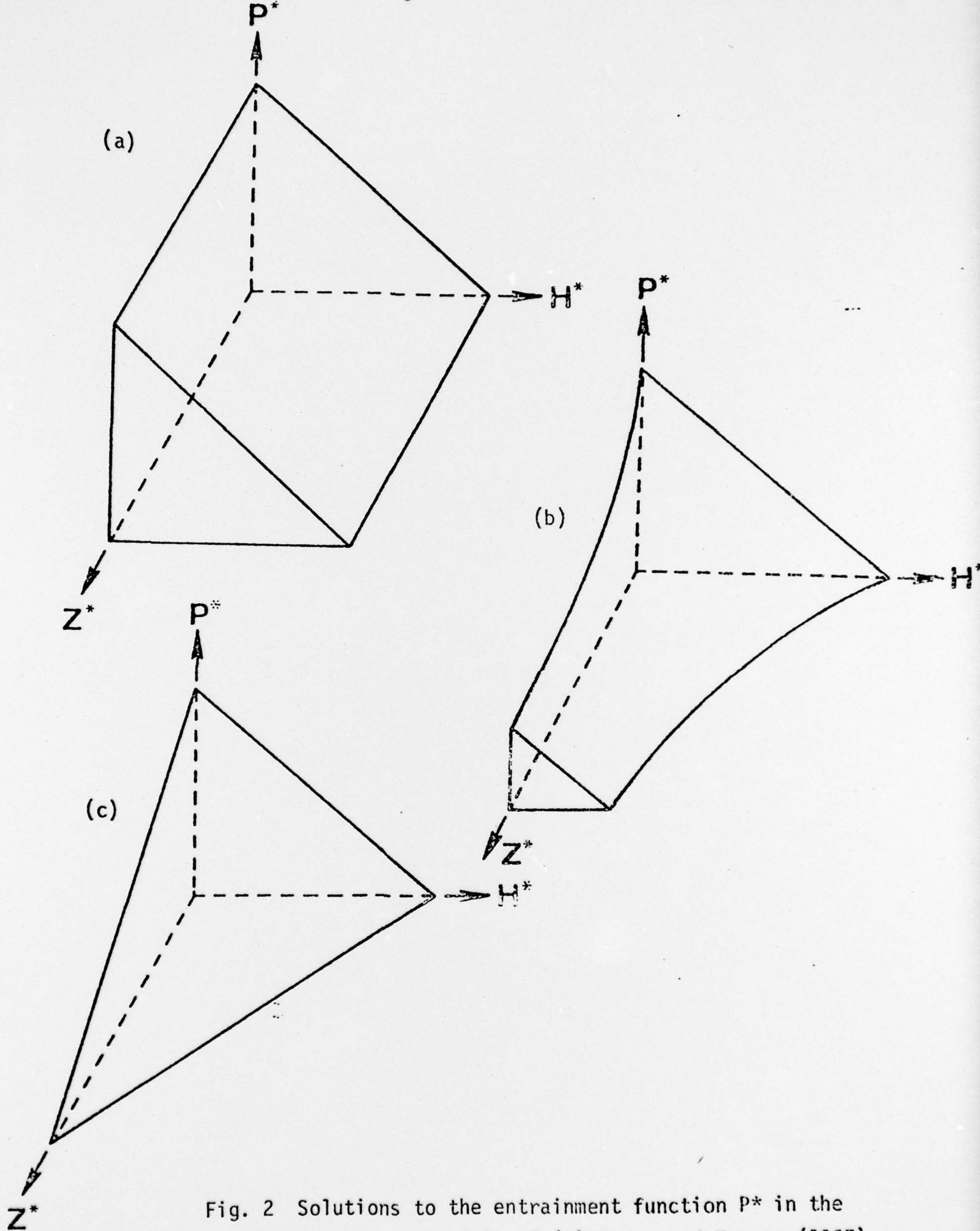
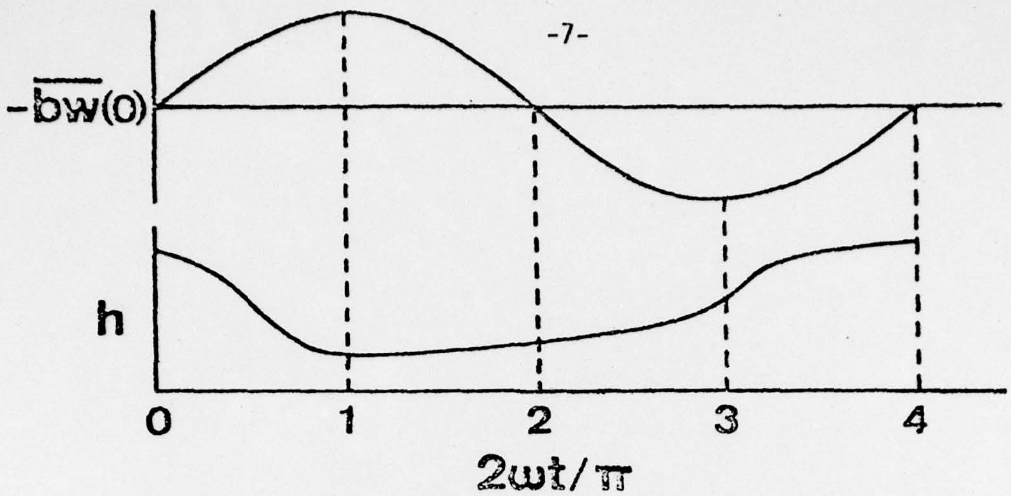


Fig. 2 Solutions to the entrainment function P* in the H*-Z* plane for the models of (a) Kraus and Turner (1967); (b) Elsberry, Fraim and Trapnell (1975); (c) Kim (1976). Compare these with Fig. 1, assuming $Z^* = Ro^{-1}$.



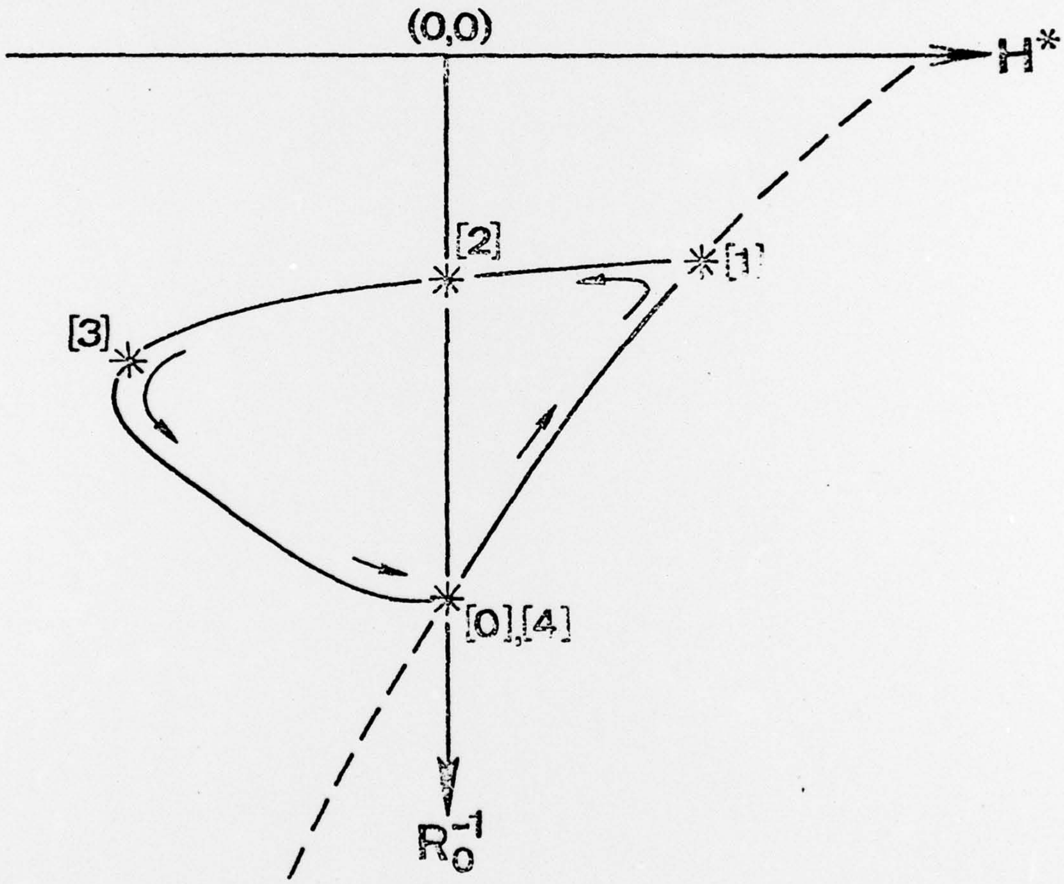


Fig. 3 Qualitative depiction of a periodic surface buoyancy flux, $\overline{bw}(0) = -|\overline{bw}(0)| \sin(\omega t)$, and a constant wind stress. This results in a cyclical h(t) response and a closed loop trajectory in the $H^* - Ro^{-1}$ plane.

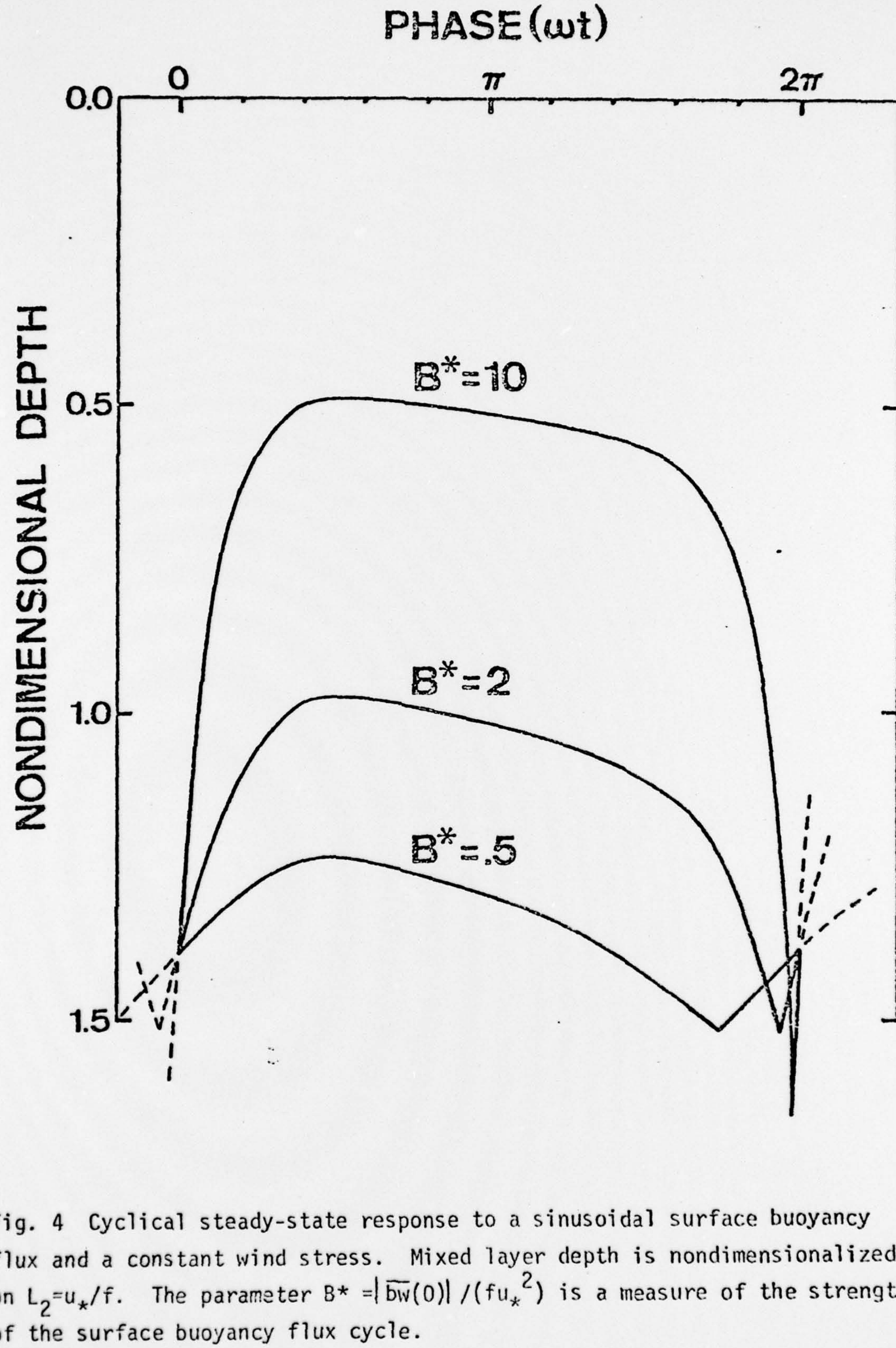


Fig. 4 Cyclical steady-state response to a sinusoidal surface buoyancy flux and a constant wind stress. Mixed layer depth is nondimensionalized on $L_2 = u_*/f$. The parameter $B^* = |\overline{bw}(0)| / (f u_*^2)$ is a measure of the strength of the surface buoyancy flux cycle.

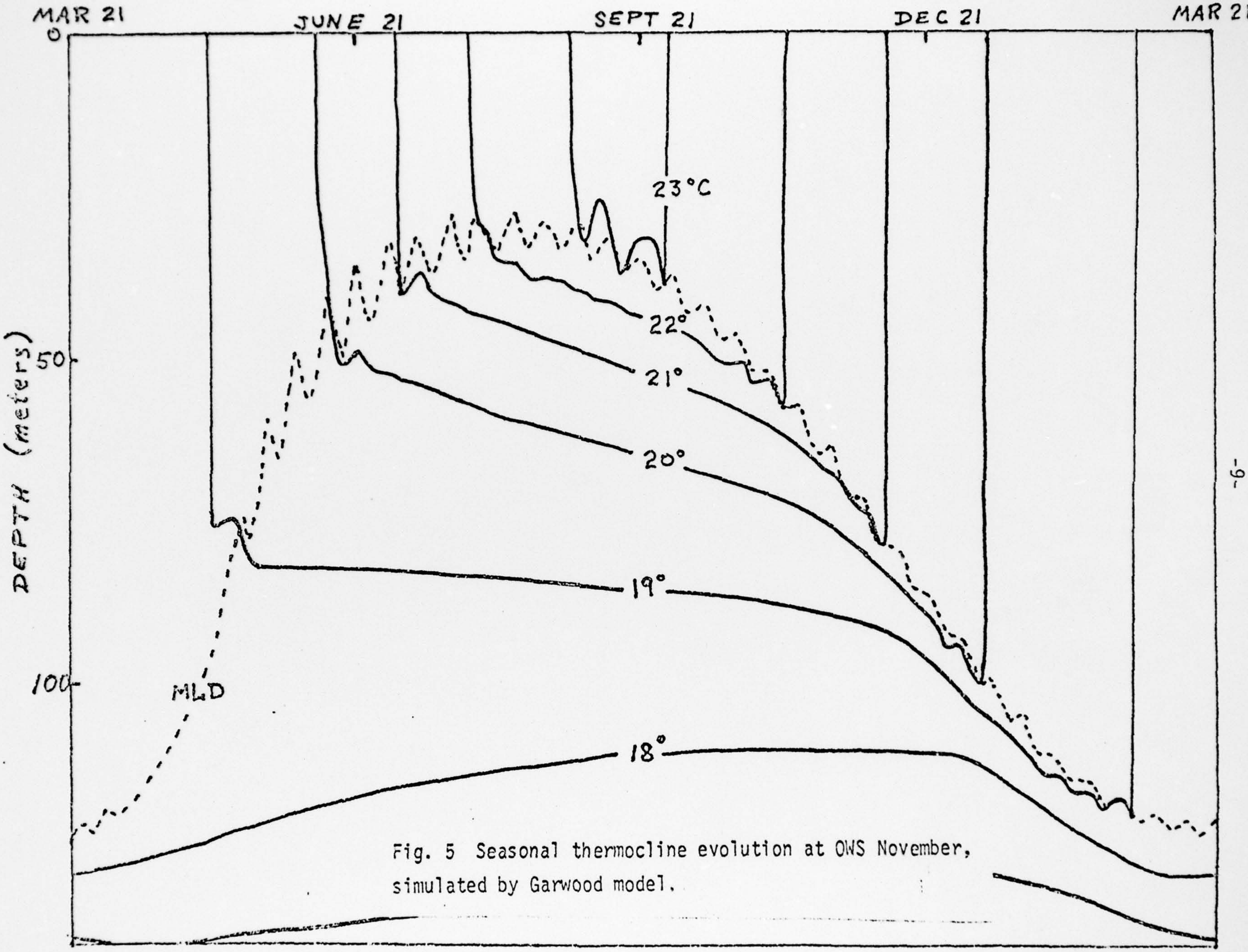


Fig. 5 Seasonal thermocline evolution at OWS November, simulated by Garwood model.

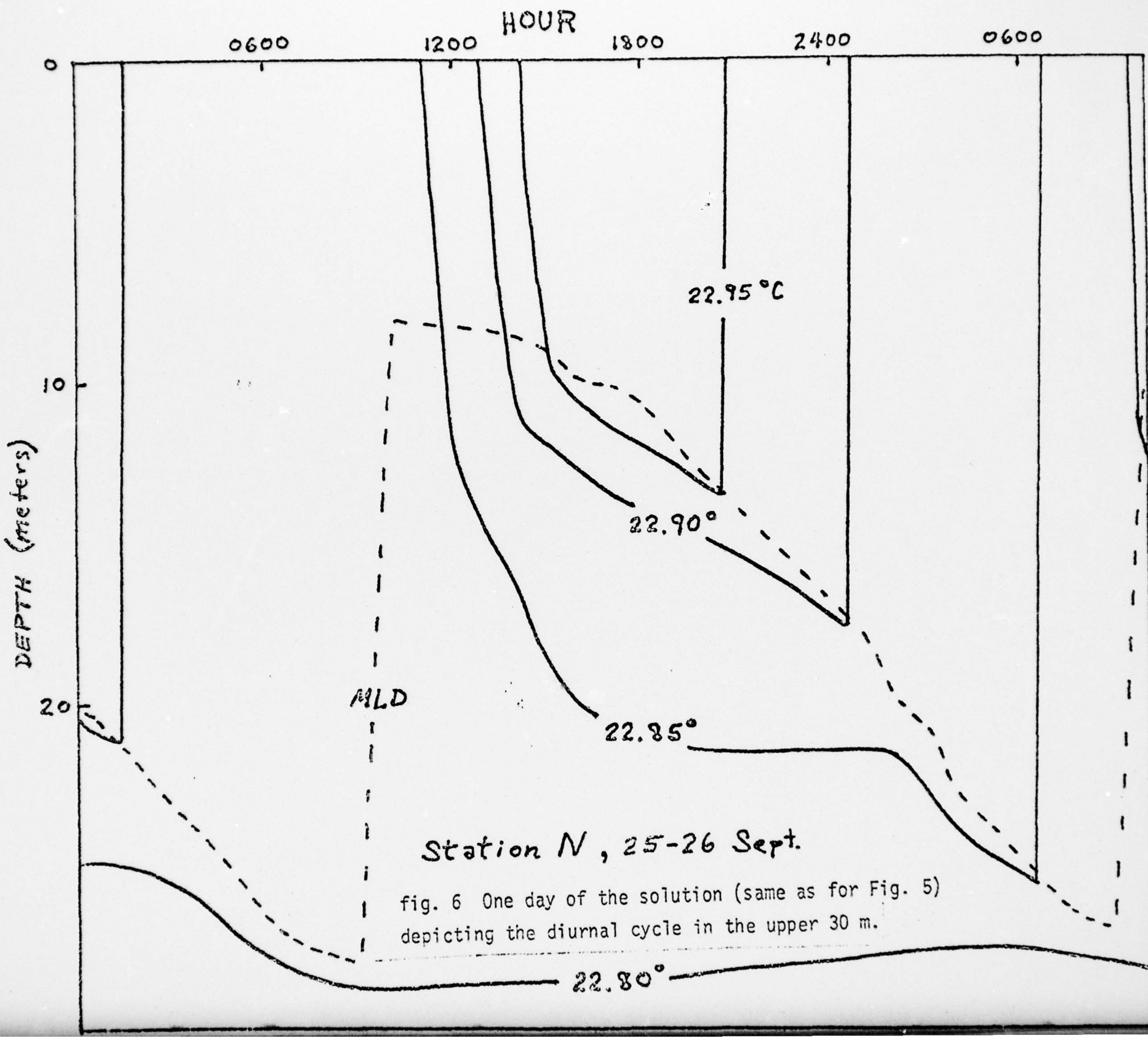


fig. 6 One day of the solution (same as for Fig. 5) depicting the diurnal cycle in the upper 30 m.

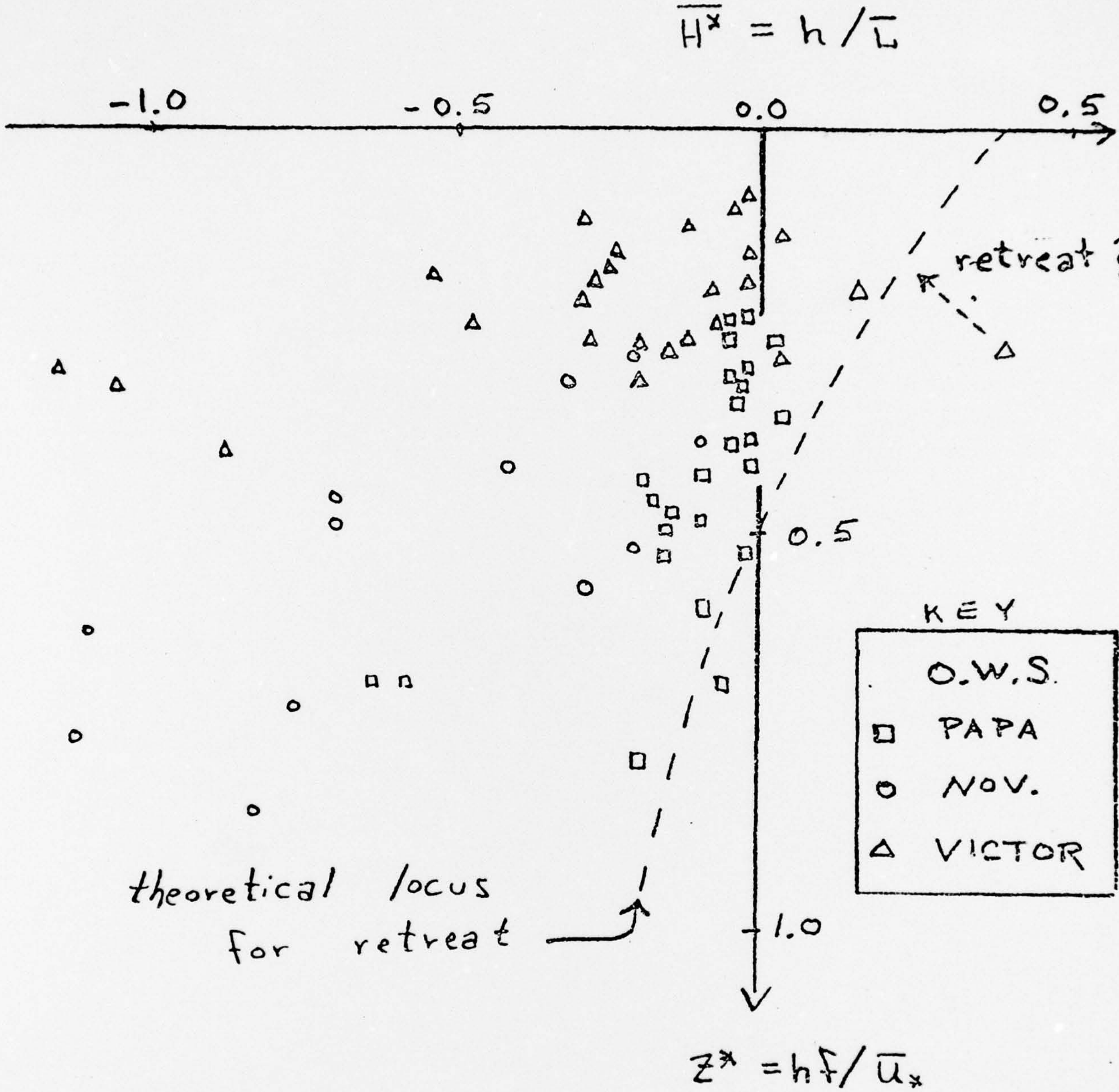


Fig. 7 Data of Camp (1976) in the $\overline{Z}^*$-$\overline{H}^*$ surface as defined by daily averages of the surface forcing scales. Mixed-layer depth here is defined as the depth having a temperature 0.2°C below the sea-surface temperature.